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LAKE PASSAIC—AN EXTINCT GLACIAL LAKE.[1]

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LAKE PASSAIC is the name given by Professor Cook in 1880 to an extinct glacial lake supposed to have existed in northern New Jersey during the last glacial epoch. Although the existence of the lake has been called into question, recent work has shown that Professor Cook was right in his main conclusion, although he was not in possession of the large body of facts which together demonstrate that conclusion. The lake occupied the basin-like area between the curving trap ridges, known as the Watchung or Orange mountains on the southeast, and the gneissic highlands on the northwest. Its northeastern end was in the vicinity of Little Falls, and its southwestern near Liberty Corner.

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[1] GEO. H. COOK. Annual Report of the State Geologist of New Jersey, 1880; pp. 61–64. ROLLIN D. SALISBURY. Ibid., 1892; pp. 126–144. ROLLIN D. SALISBURY and HENRY B. KÜMMEL. Ibid., 1893; pp. 225–328. HENBY B. KÜMMEL. Thesis for the Degree of Doctor of Philosophy, University of Chicago, July 1895 (In Press).

The basin is now drained in a roundabout way by the Passaic river, which finally escapes across the Watchung mountains at Little Falls and Paterson. Of the Watchung mountains it was the Second which formed the rim of the basin in which the lake lay.

The height of the Passaic river where it crosses this mountain at Little Falls is 158 feet. During the life of Lake Passaic, this outlet, as well as the valley now occupied by the Pompton river was choked by glacier ice. Leaving the Pompton valley and the Little Falls Pass out of account, there is no other break in the rim of the lake basin lower than 331 feet. At this altitude there is a pass across the enclosing trap ridge at Moggy Hollow, about two miles west of Liberty Corner, at the southwestern end of the basin. This outlet regulated the level of the lake for a considerable period of its history.

Within the area of the lake there are several trap ridges, of which Long Hill, extending from Chatham to Basking Ridge, is the most important. Its general course corresponds with the longest diameter of the lake. The lake basin is divided in the direction of its shortest diameter into two nearly equal parts by the terminal moraine between Chatham and Morristown.

The record of itself, which Lake Passaic left, consists principally of (*a*) shore features, (*b*) berg deposits, (*c*) lacustrine deposits, (*d*) a slight difference in the nature of the till within the lake basin and of that without. Most reliance is placed upon the shore features, but the other lines of evidence have much corroborative weight.

THE SHORE FEATURES OF LAKE PASSAIC.

The shore features of Lake Passaic are not conspicuously developed, and their obscurity is plainly not the result of subsequent erosion. It follows that they were never well developed. Since the size of the lake was sufficient for waves of several miles fetch, the meager development of shore features cannot be ascribed to the smallness of the lake. Since the conditions for the development of shore features seem to have been favorable at many points, their local absence and their general indistinctness is not to be explained on the basis of unfavorable conditions. We are left to conclude, therefore, that the meager development of shore features about the border of the lake is due to its shortness of life. In spite of the general fact expressed in the statements above, shore features are locally pronounced enough to be unmistakable.

The distribution of the shore features seems to be somewhat fortuitous. They are absent from some localities where their presence was to have been expected, and they are sometimes well developed where there seems to be good reason for their exceptional distinctness.

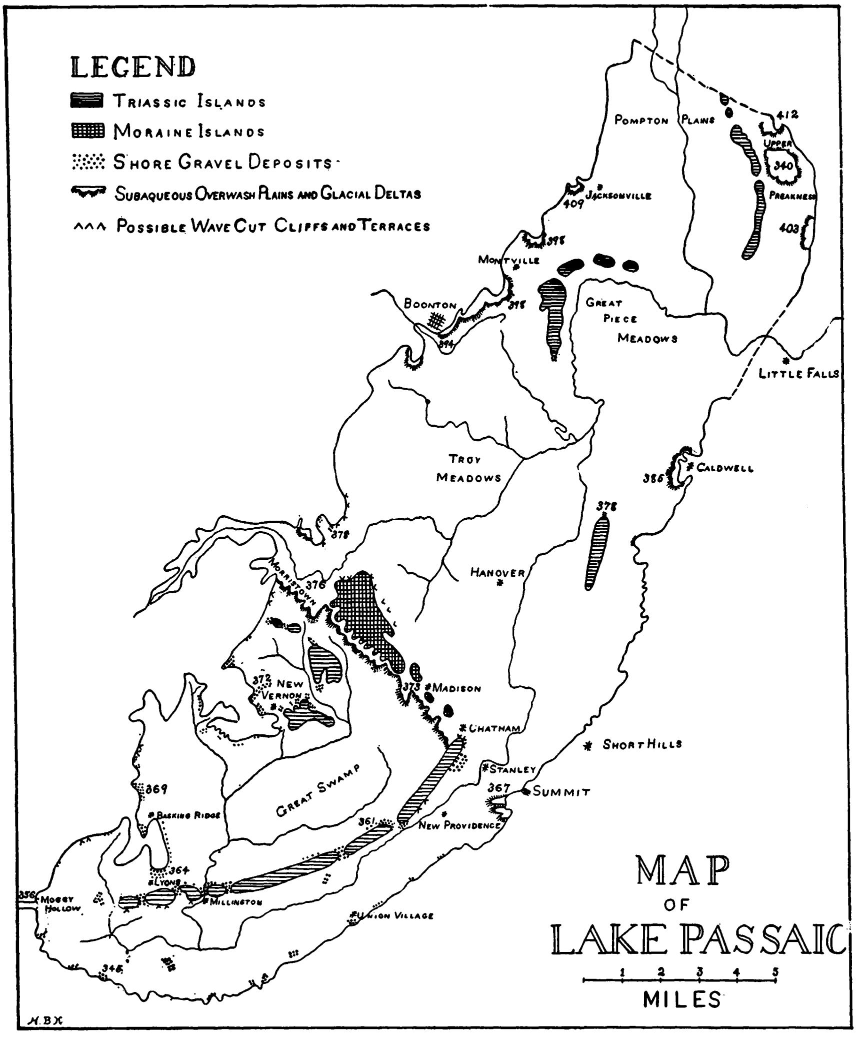
Shore features of the extra-morainic basin. A. Degradational forms.—Wave-cut terraces and lake cliffs are but poorly developed. In numerous localities, ill-defined terraces have been observed at about the level of the lake, some of which, as shown by their close connection with constructional forms, are probably of lacustrine origin. The best marked of these are upon Long Hill. At its north end, half a mile south by west of the Chatham depot (see map), there is a distinctly marked cliff and terrace. The cliff rises by a steep slope from the terrace, at the upper edge of which there are a number of drift bowlders apparently washed out of the till in which the cliff is cut. At several points on the terrace the trap rock is exposed, indicating that the terrace was formed by erosion, not by deposition. The upper edge of the terrace has an altitude of 369 feet, and is sharply defined. This wave-cut terrace can be traced southward along the eastern side of Long Hill. Its surface there becomes sandy, and it soon passes into the wave-built terrace to be seen in the lower part of the Chatham cemetery. The clearly defined cliff above the bowlder-strewn cut terrace, and the graduation of the latter into the distinct wave-built terrace, make this one of the best marked features of the extra-morainic basin.

Along the southeastern or front face of Long Hill, narrow terraces with steep rock slopes above may be observed in several places. Probably not all of them, and perhaps none of them, are to be ascribed wholly to the lake. Some of them may be benches and cliffs of differential degradation, due to the contrast in hardness between the trap and the underlying Triassic sandstone, which here and there have their junction at or near the lake level. This, however, will not account for all of them. Northwest of New Providence there is a distinctly marked bench in the sandstone, at an elevation of 367 to 369 feet. It can be traced almost continuously into a well-marked spit a mile west of New Providence. Because of this connection, especially, its reference to the lake seems proper.

Near the outlet at Moggy Hollow, a mile and a half west by north of Liberty Corner, there are slight traces of wave cutting. The phenomena are such as would be produced on a gently sloping, rocky shore against which the waves had beaten but a short time, and where the finest material had been carried away, leaving the ill-rounded pebbles where they originated. Both above and below the zone thus affected, the rock is covered by a much deeper layer of residuary soil. The height of the mean lake level at this point, as shown by other evidence, was between 351 and 356 feet.

After everything possible has been said in favor of the lacustrine origin of the terraces and cliffs found around the lake basin, it must be admitted that, were the proof of the existence of the lake dependent upon them alone, its existence could not be stoutly maintained. There is not a terrace in the extra-morainic part of the basin, the wave-cut character of which, taken by itself, can be said to be beyond question.

B. Constructional forms. 1. *On the trap, shale and gneiss*


LEGEND
Triassic Islands
Moraine Islands
Shore Gravel Deposits
Subaqueous Overwash Plains and Glacial Deltas
Possible Wave Cut Cliffs and Terraces
Pompton Plains
412
Upper
340
Preakness
403
Jacksonville
409
398
Montville
Boonton
398
394
Great Piece Meadows
Little Falls
Troy Meadows
Caldwell
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378
Hanover
Morristown
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372
New Vernon
373
Madison
Chatham
Short Hills
Stanley
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Summit
Great Swamp
369
Basking Ridge
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New Providence
364
Lyons
356
Mossy Hollow
Millington
Union Village
346
MAP OF LAKE PASSAIC
1 2 3 4 5
MILES
H.B.K.

slopes.—The constructional forms are more distinct. In a number of localities there are small but distinct spits, bars, and constructional terraces, whose heights are closely accordant one with another. In many more localities, on the slope of the lake basin, or on the slopes of the islands which stood in it, there are beds of stratified, poorly rounded, but nevertheless distinctly water-worn gravel of strictly local origin.

Although not possessing distinct topographic form, these beds of local gravel agree in height, material, and structure with the well defined constructional terraces at other points. Where the gravel is not present in beds, scattered water-worn pebbles of local origin have been found at numerous places at levels corresponding with those of the well defined shore features. So general is their presence, as to warrant the belief that the shore gravel is much more nearly continuous about the former margin of the lake than superficial inspection would indicate. Nowhere have constructional shore features, beds of local gravel, or scattered water-worn pebbles of local origin been found about the lake basin, or on the islands in the lake, above the level at which the waters of the lake could have been confined.

On Second mountain well-defined beds of local gravel have been found at thirteen points. The location and the height of the more important of these is shown on the accompanying map. With one exception they range in altitude from 344 to 369 feet A. T., while single beds have a vertical range of as much as fourteen feet. A single bed of gravel is known at a lower level—about 300 feet. On the gneiss highlands between Bernardsville and Morristown, two small deposits of wave-worn gneiss pebbles are known at elevations of 371 feet to 380 feet.

During the life of the lake, the cols of the ridge known as Long Hill were straits. At the same time, the crests above the cols constituted islands. Of these there was a series of nine. They were long and narrow, and rose above the water to heights not exceeding 125 feet. Débris carried by the waves and currents along the shores of these islands, accumulated at their ends, (in or near the present cols) as spits, bars, or beds of gravel and sand. Considerable beds of trap gravel occur in four of the cols. Water-worn trap pebbles in lesser quantity are found in all the others at accordant heights. Between the cols along the shores of the former islands, there are frequent traces of gravel identical with that of the cols at corresponding heights. Such gravel is probably more widespread and greater in quantity than is now shown, since exposures are few. Such as exist are often most insignificant. Thus on the northern slope of Long Hill, one and three-fourths miles west of New Providence, a shallow, freshly-dug trench several hundred feet in length was seen (1893). Its course was across the shore line. On the surface there was no topographical evidence of wave action, nor were the water-worn pebbles abundant enough to attract attention. Above an elevation of 361 feet, the material exposed in the trench was material which had arisen from the decay of the trap rock. Below 361 feet the trap residuary was succeeded lakeward by coarse, wave-worn trap pebbles. The gravel was roughly stratified, and contained occasional foreign pebbles. Further down the slope the gravel was succeeded by sand, and that again by gravel. A thin layer of clayey loam, the result of post-lacustrine wash from the slopes above covered the whole. This exposure proved conclusively that some agent had been at work on the lower slope, re-working and re-arranging the local material up to a certain definite level, above which it did not reach. The element of height appeared to be the only controlling factor. Waves could produce the observed phenomena; running water could not. This significant exposure showed that the absence in some localities of topographic shore features, and of rounded surface gravel, does not militate against the lake hypothesis.

In addition to the beds of gravel on Second mountain and Long Hill, similar deposits occur at the proper heights upon the hills near New Vernon and south of Morristown.

A few of the constructional shore features deserve separate mention. (*a*) In the lower part of the cemetery of Chatham, there is a high, well marked, wave-built terrace of sand and gravel, to which reference has already been made. It is composed of glacial gravel, derived from the till which covers this end of Long Hill. The elevation of its upper edge is 369 feet A. T. (*b*) A wave-built terrace of trap gravel, 100 to 150 yards wide, is found just north of Lyons Station, at the southern end of what was a peninsula. Northward from this terrace along the shore line rounded pebbles of local origin occur in considerable numbers. As the red shale rises to the lake level at Basking Ridge the shale pebbles become more abundant in the shore gravels, while the trap pebbles become proportionally less. (*c*) Southwest of Moore's hotel, Basking Ridge, where the old shore line has an elevation of about 367 feet, there is a broad wave-built terrace at the head of what was a small bay. The gravel of which it is composed is chiefly from the local shale. (*d*) Near the sag in Long Hill, a mile and a quarter west of New Providence, there is a short but pronounced spit. Northeastward it is continuous with what may be a wave-cut terrace, as elsewhere noted. The gravel is chiefly of red shale, derived from the subjacent terrane. In cross-section the lines of bedding are seen to dip outward, forming what may be called anticlinal stratification. (*e*) Another short spit occurs about three-quarters of a mile west by north of Berkeley Station. Its elevation is somewhat (45–50 feet) less than the maximum level of the lake.

The composition of these gravel beds, considered in relation to the underlying and adjacent indurated formations, is most significant. On Second mountain—a great trap ridge—the gravel deposits attributed to shore action are composed almost wholly of fragments or pebbles of trap, with only occasional foreign pebbles. The same is true, in the main, of Long Hill, though on the south side of this ridge the red shale occasionally rises to the level of the lake. Where gravel beds are found on shale slopes instead of trap, shale has made the principal contribution. The spit west of New Providence is an instance in point. Where the shore of the lake was against a drift-covered slope the gravel beds are composed of drift gravel. The terrace in the cemetery of Chatham is an illustration. In the vicinity of Basking Ridge, deposits of trap gravel grade into those of shale where the shore line passed from the trap to the shale. Along the gneiss highlands the two gravel beds known along the margin of the lake, are largely of gneissic gravel and sand, and local sources for the other constituents are at hand. Near New Vernon the gravel deposits on the trap hills are mainly of trap, those on the shale are composed chiefly of shale, while those on the Triassic conglomerate are of quartzite pebbles, derived from the conglomerate itself. The foreign pebbles in the shore gravels may belong (*a*) to the older drift, remnants of which occur at various points about the lake; or (*b*) they may have been transported along the shore of the lake from the newer drift; or (*c*) they may have been carried to the shore of the lake by blocks of floating ice, starting from the moraine.

Waves and shore currents are the only known agencies which can develop water-worn, stratified gravel, sustaining this definite relationship to the adjacent and subjacent formations. The topographic situation of some of these shore deposits of gravel, taken in connection with their composition, is such as to admit of no second interpretation. Generally speaking, they occur along a horizontal belt at a definite elevation, either (*a*) on the slopes of higher lands, or (*b*) in the passes and cols between them. Above this definite level, gravel such as described does not occur. Below this level, such beds of gravel occur as might have been formed during the later stages of the lake's history, when its level was sinking and its area diminishing.

A careful study of the shore deposits, particularly their relations to headlands of rock and wave-cut benches, gives us some knowledge of the general direction of the waves and shore currents. On Long Hill the shore drift traveled, in general, southwestward, as shown by the terrace near Chatham, the spit west of New Providence, and the spit west of Berkeley station. Near Basking Ridge the material was carried southward, as shown by the shale gravel southwest of Moore's hotel, and the trap gravel at the south end of the ridge near Lyons. Three different deposits on the hills a mile and a half south of Morristown were clearly formed by westward moving currents.

Three particularly favorable classes of localities for the deposition of the shore gravels can be made out. These are (*a*) in the shallow, narrow straits between islands, the numerous deposits along Long Hill being the most marked examples; (*b*) at the ends of the islands or peninsulas where the shore currents (1) kept their course as the island was passed, spits being the result, the spit near New Providence being a good example; or (2) where the shore currents lost their velocity by spreading, in which event terraces were formed, the terrace just north of Lyons being an example; (*c*) at the heads of small converging bays, the terraces west of Basking Ridge and east of Bernardsville being good examples.

2. *On the outer face of the moraine.*—In addition to the constructural shore features already described, there are still others in the extra-morainic part of the basin which testify in no doubtful way to the former existence of Lake Passaic. The outer face of the terminal moraine, in so far as it lies in the lake basin, is bordered by a subaqueous overwash plain[1] of goodly proportions. The special characteristics of deltas and subaqueous overwash plains are flat tops, sloping gently from the head to the front, a steep front slope (indicated by hachures on the map), a lobate margin with deep re-entrant angles and projecting cusps, and a tripartite structure, as seen in vertical section. This structure consists of (*a*) nearly horizontal beds at the top, underlain (*b*) by beds dipping steeply towards the front, and these in turn rest upon (*c*) horizontal or nearly horizontal layers of fine material. All these features are illustrated by the plains bordering the moraine on its outer face. Thus near West Summit there are three prominent marginal lobes on the subaqueous overwash plain. West of Madison, the flat top of the plain is a third of a mile wide, with a fall of about ten feet in this distance, whereas its steep front falls off 60 feet in 100 to 200 yards. Southwest

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[1] An overwash plain made in standing water. See Annual Report of the State Geologist of New Jersey, 1892, p. 41.

of Convent station the top of the plain is half a mile wide. From its upper edge at the moraine it slopes gently to the southwest, declining 20 to 25 feet in the half mile. Here it falls off abruptly, with a slope which declines about 50 feet in 125 to 150 yards. While no single exposure was found which showed the complete tripartite structure, exposures were seen which showed the several beds individually, and there can be little doubt that good exposures would reveal the three in vertical section.

The line marking the junction of the gently sloping upper surface of the plain, with its abrupt front, marks the approximate water level at the time the plain was finished. But when it is desired to fix the water level exactly, or even within two or three feet, many inconsistencies seem to be involved if it be assumed that the line marking the change of slope corresponds accurately with the water level. There are several reasons for believing that it does not. (*a*) It has been found that even where the change of slope is most marked and can be accurately fixed, its height varies three, five, or even seven feet within comparatively short distances. (*b*) A consideration of the manner in which glacial delta plains are formed shows that the prônounced change of slope must mark the point where the bottom current of the running water which was rolling the débris, so far lost its velocity that its load was dropped. It would seem, therefore, that the upper edge of the steep slope cannot be built nearer the surface of the lake than the depth of the current which, at that particular point, is supplying detritus. Since the depth and velocity of the various streams supplying detritus were different, and since a subaqueous overwash plain was built by a number of streams or by the distributaries from a single stream, all of which have various depths and velocities, the upper limit of the frontal slope should be of varying heights on adjoining lobes, and might even vary to some extent on the same lobe. We conclude, therefore, that the lake level was somewhat (perhaps sometimes several feet) higher than the upper edge of the highest "fronts," and that the water covered the outer and lower part of the gently sloping top. The depth of the submergence at different points would depend upon local conditions.

From data supplied by the other shore features, it seems probable that west of Madison, the lake shore corresponded approximately with the present elevation of 373 feet, covering nearly all of the plain whose outer edge has an altitude of 362–5 feet; that west of Convent the shore corresponded approximately with the present level of 374 feet, the outermost lower edge of the plain having an altitude of 356 to 364 feet, and the upper edge of 382 feet; and that at West Summit the former water level has a present elevation of 367 feet, whereas at this point the outer edge of the plain has an elevation of only 345 to 356 feet, rising to about 380 feet at its moraine edge. It is perhaps not necessary to suppose that the edge of the plain was developed contemporaneously at these several points, or that the level of the lake was absolutely constant.

The subaqueous overwash plain bordering the moraine is a very considerable one. Since deposits of this sort may be of very rapid construction, a long period is not demanded for its growth.

SHORE FEATURES OF THE INTRA-MORAINIC BASIN.

The shore features of the intra-morainic portion of the basin differ in several important respects from those of the extra-morainic basin. These differences are due to the different conditions which prevailed in the two parts of the basin. The intra-morainic part of the basin was occupied by ice for a portion of lacustrine time. Its lake history, therefore, must have been briefer than that of the extra-morainic portion. In so far as it was briefer, its shore features should be less strongly developed than those of the extra-morainic portion of the lake. On the other hand, since the glacier left thick deposits of sand, gravel, and till upon which the waves could readily work, and since an enormous amount of loose material was furnished to the lake directly by the melting ice, constructional terraces, spits, bars, etc., could have been rapidly built under these favoring conditions. The abundant supply of shore and glacial-stream drift might even more than compensate for the shorter life of this part of the lake. It is to be remarked that deposits of water-worn gravel in this part of the lake must possess the structure and topographic forms characteristic of shore deposits. Otherwise they are no proof of the existence of the lake, since streams from the melting ice might form beds of gravel at any elevation, within or without the lake basin.

Degradational features.—Within the intra-morainic basin, there are no terraces which can be asserted to be wave-cut. On the inner face of the moraine, between Chatham and Littleton, there are discontinuous, often bowlder-strewn terraces in the drift, sometimes limited above by steep cliff-like slopes. They may be of lacustrine origin. On the east shore of the lake between Summit and Caldwell, particularly east and southeast of Livingston, benches have been observed, which resemble wave-cut terraces in some respects. Similar benches occur at one or two other points. In themselves these terraces would be an insufficient basis for affirming the existence of a lake in the intra-morainic part of the Passaic basin. They may, however, have some corroborative significance.

Constructional features.—The chief constructional shore features of this part of the basin are deltas, built in immediate juxtaposition to the ice, by heavily laden glacial streams. Under such conditions the supply of material was great and the growth of the deltas rapid, resulting in the production of very considerable plains in a comparatively brief time. The deltas are numerous and decisive in character. They occur in greater numbers, and in better development on the west and northwest sides of the lake, than along its eastern shore. The most important of them are represented on the map, their steep fronts being shown by hachures.

A mile north of Parsippany, there is a gently sloping, slightly undulatory plain of sand and gravel, having an area of a quarter of a square mile. It has the lobate margin, steep front, and re-entrant angles characteristic of deltas. Its lobes rise thirty feet above the lower land to the south and west. Northward, the plain passes into an irregular kame area, which it is believed marks the site of the ice edge during the formation of the delta. The water level corresponded to the present elevation of 394 or 395 feet.

Between Boonton and Montville, southeast of the canal, there is another glacial delta having an average width of half a mile or less, and a length of two miles. Towards the upper limit of the plain, bowlders are numerous, and the surface somewhat irregular. Patches of till are also present, apparently indicating that the ice lay on the higher ground to the northwest during the formation of the plain. The general level of this plain is less than 400 feet. Along much of the front of this delta, there is a lower terrace marking a stage of the lake 70 to 75 feet below the maximum stage.

Just north of Montville there is a perfect example of a glacial delta, having an area of about a quarter of a square mile. The top slopes gently from north to south, and then falls off abruptly for 70 to 90 feet. Its margin or front is distinctly lobate. The water level here seems to have been along a line which now has an elevation of 397 to 398 feet.

A mile and three-quarters north of Whitehall, and west of the Jacksonville schoolhouse, there is another small delta, whose frontal lobes are well marked. This deposit indicates a shore-line having an elevation of 408 to 410 feet.

The largest and most typical delta of Lake Passaic occurs at Upper Preakness. Its surface is nearly flat. Its margin is strongly lobate, falling off abruptly 50 feet. Its area is about one square mile. Its elevation, 335 to 340 feet, indicates a lake stage about 70 feet below the maximum in this region. It is to be correlated with the lower terrace on the Boonton delta. Just north of this plain is a moraine-like kame belt, half a mile in width. The hillocks are of coarse material, and are often thickly strewn with bowlders. At the same time that the Upper Preakness delta was building, the kame belt was probably formed just beneath the ice and at its irregular margin.

North of the kame belt is another but more irregular plain of sand and gravel, the surface of which seems to have been more or less modified, by the action of standing water. To have extended over it, Lake Passaic must have covered a surface which now has an elevation of 412 feet.

A mile and a half west of Haledon, near Paterson, there are delta-like terraces at two levels. They mark water levels which now stand at 412 feet, and 340 feet respectively. In the vicinity of Caldwell, also, there is a somewhat extensive sand and gravel plain, which has a similar significance.

Of the glacial deltas and terraces, those (*a*) at Montville, (*b*) west of Jacksonville, and (*c*) at Upper Preakness, are the most typical. The northern margins of the two last named have the irregular, hummocky surfaces characteristic of gravel beds, which were originally built against the ice, but which have since slipped and fallen down as the ice melted. In places the slopes still retain the irregularities of the ice mold in which they were cast. Several of the other plains pass into kame areas, which are believed to have been formed beneath the ice and at its irregular edge and to mark the position of the ice front, at the time of the formation of the deltas. In a number of cases, kames of an older generation have been partially buried by the advancing front of the growing deltas.

In addition to the deltas, there are a few small spits connected with what appear to be wave-cut terraces, and a few kames whose summits seem to have been truncated by the waves; but aside from the glacial deltas, the constructional shore forms are not conspicuous or decisive. The largest deltas within the moraine may have required far less time for their building, than the gravel beds along the trap ridges in the extra-morainic part of the lake.

THE LACUSTRINE DEPOSITS OF LAKE PASSAIC.

Iceberg deposits.— Iceberg deposits in the extra-morainic part of the lake basin consist mainly of bowlders similar to those of the moraine. They are found frequently up to altitudes of 340 feet, and more rarely up to the maximum level of the lake. Although distributed widely over the area of the basin, they are particularly conspicuous on the low land in the immediate vicinity of Moggy Hollow outlet.

Bowlders of granite, gneiss, quartzite, and conglomerate are found at some points above the probable shore-line on the trap ridges. As compared to the bowlders of corresponding material below the shore-line, their greater age is shown by their greater decomposition. They are regarded as remnants of a pre-morainic sheet of drift.

North of the moraine, iceberg deposits cannot be differentiated with any degree of certainty from the deposits formed directly by glacier ice.

Clays and silts.—Clays and silts, which are believed to be lacustrine, are very generally present over the low areas of the extra-morainic basin. They underlie all the area of the Great Swamp and its immediate surroundings. Within this area they do not occur above an altitude of 240 feet. Somewhat similar clay has been found in a few places at higher levels, but always much below the highest shore-line. The clay of the eastern half of this area is covered with fine, sandy loam, which, as the moraine is approached, grades into sand and gravel. Though more or less buried by stratified drift, clay also occurs south of Morristown, southwest of Convent, and southwest of Madison. These relationships show that the lacustrine clay passes under, and therefore antedates the moraine and its contemporaneous overwash plain. The upper part of the clay may represent the bottom-set beds of the extra-moraine stratified drift.

In the Great Swamp area the clay attains great thickness. Wells 25 or 35 feet deep do not pass through it. A mile and a half south of Green Village it was penetrated to a depth of more than 100 feet, although there is no positive evidence that all this deposit is lacustrine. The lacustrine clay is "fat" or "greasy," and a little below the surface is finely laminated, the laminæ of clay being separated by fine partings of a more sandy nature. It is highly calcareous, and frequently contains concretions of carbonate of lime. These concretions are very abundant at certain horizons, in various localities.

Clays which are of the lacustrine type have been found at several localities in the intra-morainic portion of the basin. They are similar in general appearance to those outside of the moraine. They are generally at low levels, and in places are associated with clays which may be post-glacial in origin. In some places this clay is covered by till. Where this is true, the relations suggest either (*a*) that the clay belongs to an early period of the lake's history, if it be lacustrine at all, or (*b*) the till over it is berg till, or (*c*) till deposited by the ice during a temporary re-advance in the general period of its treat.

The till of the intra-morainic part of the basin.—Much of the till of the intra-morainic part of the lake basin is not of the normal type. This abnormal phase is stony, but not gritty. On the contrary, it is very clayey. It has a more or less greasy feeling, a waxy or glazed surface when cut, and a pronounced tendency to crack on drying. Many of the pebbles are coated with a thin film of clay, which is not easily removed. The color is dark red, tinged with brown. This type of till occurs most commonly at low levels. It has nowhere been found up to the level of the shore-line. Normal till is not uncommon within the lake basin, and it sometimes occurs in close proximity to the type noted above.

It is not possible to say to what extent this abnormal type of till was formed beneath the ice, and afterwards submerged, and to what extent it was formed beneath water by icebergs floating on the lake. A somewhat similar, waxy, clayey character affects much of the soil on the red shale in the extra-morainic part of the basin, a characteristic foreign to unmodified red shale residuary.

THE OUTLETS OF LAKE PASSAIC.

The Moggy Hollow outlet.—A mile and a half west by north of Liberty Corner, at Moggy Hollow, there is the notch in the rim of the basin, through which Lake Passaic drained during its maximum stage. The bottom of the notch has an altitude of 331 feet, and with the exception of the gaps at Little Falls and Paterson and the low ground along the Pompton river, all of which were closed by the ice when the lake existed, this is the lowest point in the rim of the basin. The notch is a flat-bottomed, steep-sided trench, 60 yards wide at the bottom and 157 yards wide at the height of the maximum lake level. It is cut in hard trap rock, which outcrops at many points on the sides and bottom of the trench. Its form is altogether conclusive that it was the channel through which flowed a stream of water, whose average width was about 150 yards, and whose depth was sufficient to give it great velocity. In pre-lacustrine times there may have been a col on the site of the notch, but the notch in its present form is due largely to erosion by the outflowing current of the lake. Through this outlet the drainage of the lake entered the North Branch of the Raritan.

The Millington gorge.—The Passaic river escapes from the area of the Great swamp by a deep narrow gorge through Long Hill, at Millington. The gorge is 60 to 70 feet deep, very steep sided, and, so far as shape is an index, seems to be of very recent origin. So young does it appear, that the hypothesis was for a time entertained, that it was largely or wholly post-glacial. This hypothesis was finally abandoned because of the small amount of trap gravel in the valley below the gorge (too little by far to fill it), and because of the evidence afforded by the Stanley gorge, as to the amount of post-glacial cutting by the Passaic. This evidence is cited below.

The Stanley outlet.—Near Stanley, the Passaic river has cut a passage through a drift barrier in post-lacustrine times. The amount of post-glacial cutting is here 25 to 30 feet of which 18 feet is in drift, the remainder in red shale. The passage which the river has cut here is much wider, much less steep-sided, and less deep than the gorge at Millington. The differences in width and slope may well be due to the differences in the hardness of the material. The difference in depth between the post-glacial cut at Stanley, and the gorge at Millington is most significant. All conditions seem to favor erosion at Stanley, as compared with Millington:—(*a*) the size of the stream is greater at Stanley; (*b*) its gradient is slightly greater; and (*c*) the material in which it has cut is very much more easily eroded. If, under these circumstances, the post-glacial cutting at Stanley has been no more than the figure cited above, the amount of post-lacustrine erosion at Millington gorge must have been much less.

Before being lowered by erosion, the drift dam at Stanley had an elevation of about 230 feet. After the ice freed the Little Falls-Paterson outlet, a long, narrow lake must have had a temporary existence behind this barrier, in the valley between Second mountain and Long Hill. Its greatest depth could hardly have exceeded twenty feet. All the lacustrine clay between Long Hill and Second mountain lies below this level, and furthermore most of the surface below this level is clay-covered. There is little doubt that such a lake existed for a time after the great body of the water of Lake Passaic had drained away. It was lowered as the Stanley gorge was cut down, and disappeared when the outlet was cut to the level of its bottom.

The Little Falls outlet.—Where it is crossed by the Passaic river at Little Falls, Second mountain is broken by a gap more than two miles wide. The bottom of this gap is nearly flat, and is covered with a coating of till, clay and fine sand, not exceeding ten feet in depth, where now cut through by the river. It is certain that the level of the outlet which Lake Passaic found via Little Falls after the retreat of the ice, had an altitude of not more than 190 feet, and not less than 175.

At West Paterson, the Passaic river crosses First mountain through a gap two miles wide. When the ice had melted back so far as to open this outlet, the river must have crossed this ridge at an elevation of not more than 150 feet, and not less than 125 feet. Since this height is at least 12 feet lower than the height of the lowest swamps in the lake basin, this rocky barrier could not have caused subordinate lakes within the Passaic basin.

Great Notch.—Three miles south of Paterson, First mountain is cut by a narrow gap, whose bottom is 303 A. T. Under certain conditions this gap might have served as an outlet for a brief period. Examination of the gap failed to reveal data which could be regarded as proving either that the lake did or did not drain through it at any time.

The drift-filled gap at Short Hills.—West of Short Hills the crest of Second mountain is broken by a sag whose bottom has an elevation of 380 feet, an elevation 170 to 200 feet lower than the average height of the trap crest of the mountain. The terminal moraine crosses Second mountain through this sag. Some years since a deep well was bored just below the summit of this sag at an elevation of 370 feet. The well was sunk 200 feet *without reaching the trap rock.* The rock bottom of this gap, therefore, must be below 170 feet A. T. There is good reason to believe that it is much below this figure. A quarter of a mile east of the Short Hills depot, at an elevation of 200 feet, there is a well 200 feet deep. At this depth, that is at sea level, rock was reached. This well is located in the shale valley between First and Second mountains, and is in line with the gaps in Second mountain west of Short Hills, and in First mountain at Millburn. These facts and relations clearly indicate a deeply buried channel across Second mountain at Short Hills, and across First mountain at Millburn, the rock bottom of which at one point between the two trap ridges, is known to be at sea level. If the rock bottom at the gap in Second mountain be no lower than 170 feet—the bottom of the boring—the preglacial stream must have had a fall of 170 feet on the south face of Second mountain. The width of the gap is such as negative this conclusion. It is so great as to indicate that the stream which occupied it was of considerable age. It is probable, therefore, that the bottom of the rock gap in Second mountain is very much lower than 170 feet, the height at which the boring ceased.

It follows, therefore, that the main drainage of the Upper Passaic basin in preglacial times was almost certainly through the Short Hills and Millburn gaps. Manifestly Lake Passaic could not have come into existence until the first of these gaps was closed by the ice and drift.

THE HISTORY OF LAKE PASSAIC.

Something can be inferred as to the preglacial drainage of the lake basin from the gaps in its rim. Through the lowest gap, that at Short Hills and Millburn, the larger part of the preglacial drainage of the Passaic basin doubtless escaped. It is probable that another stream of less size, draining the northeastern part of the Passaic basin, flowed through the gaps at Little Falls and Paterson. The drainage areas of these two basins could have been separated by no more than a low divide, as shown by the present topography.

The advance of the ice.—When the ice sheet closed the gap at Little Falls, the drainage must have accumulated in front of the ice in the northern basin referred to above. Any lake which may have been formed at this time must have been small and shallow, for it must soon have overflowed the low divide which separated the drainage basin having its outlet at Little Falls, from that which had its outlet through the Short Hills gap. As the ice advanced, it encroached upon this hypothetical lake, displacing its water and diminishing its area and finally destroying it altogether.

No lake could have been formed in the drainage area of the river which flowed through the Short Hills gap, until after the ice reached that gap and filled it. Then, and not until then, could a lake have existed in the basin south of Morristown. So soon as this gap was closed, water from the melting ice began to accumulate in that part of the basin which the ice did not fill. This was the beginning of Lake Passaic. The water rose until it reached the level of the Moggy Hollow outlet, through which it drained. As already stated, the bottom of the notch in the rim of the lake basin at this point, is 331 feet above tide. During the period when this notch served as the outlet, erosion is believed to have lowered it not more than 25 feet.

The Madison stage.—When the ice had blocked the Short

Hills gap, Lake Passaic began its existence. Since the ice of the last epoch had then reached its maximum extension, the area of the lake was at a minimum. The lake seems to have remained at approximately the same level during the time when the moraine and the subaqueous overwash plain which borders it were formed. During this period of maximum level there were formed, in part at least, the high-level shore lines in the extra-morainic basin. To this stage belong the broad, subaqueous overwash plain extending from Chatham to Morristown, and perhaps also the somewhat lower plains near West Summit, the gravel deposits near Bernardsville, Basking Ridge, Lyons, Millington, New Providence and New Vernon, as well as others of less importance. This stage of the lake may be called the Madison stage, from the fine development of the subaqueous overwash plain west of that place. During this period there were doubtless minor oscillations of the water level, due chiefly to varying rates of melting of the ice. Such oscillations of level may perhaps explain some of the minor inequalities in the heights of the different lobes of the subaqueous overwash plain.

The retreat of the ice.—As the ice melted back from the moraine, the lake increased in area by successively filling those parts of the basin from which the glacier withdrew. During this period, the lake must have been more or less completely divided into two parts by the moraine, which, for part of its course across the basin, rises above the maximum water level. This barrier did much to prevent débris-bearing icebergs from reaching the extra-morainic basin, and thus limited the time, during which berg deposits could be made outside the moraine, to the period of ice advance.

During the retreat of the ice, an embayment of several miles affected the front of the glacier, where it crossed the basin of the lake. The glacial deltas between Boonton and Parsippany, southeast of Boonton, north of Montville, at Jacksonville, Upper Preakness and Caldwell, were all formed by glacial streams while the ice edge was in the immediate neighborhood. The ice seems to have remained upon the higher ground above and back of these plains, after it had retreated from the lower ground in the same latitude, thus giving rise to the embayment. This is shown (*a*) by the basin-ward slope of the surfaces of the foregoing delta plains, showing that they were built from the highlands; (*b*) by the forward-plunging strata, which, where seen, generally dip towards the lake and away from the highlands; (*c*) by the frequent occurrence at the head of the plains, of bowlder-strewn kames, which mark the position of the ice edge while the plain was forming; and (*d*) sometimes by the forms of the margins of the deltas. Other possible modes of origin were kept in mind as working hypotheses in the field, but were finally abandoned, since they did not harmonize with the facts.

The Upper Preakness stage.—At a number of places more or less well-defined terraces and deltas are present at elevations from 65 to 75 feet lower than the maximum water level. These lower terraces are sometimes directly in front of the higher, which then rise from the upper margin of the lower. In other localities the higher are present without the lower, or the lower without the higher. The two are seen in close connection between Boonton and Montville, at Upper Preakness, and west of Haledon. On the assumption that the tops of these lower terraces represent the approximate level of the water in which they were formed, just as it has been assumed that the surface of the subaqueous overwash plain marks the maximum water level, these terraces mark a subordinate stage in the lake's history. This stage may be called the Upper Preakness stage, from the marked development of the delta plain near Upper Preakness. The field relationships are such as to indicate beyond reasonable doubt that *the lower terraces antedate the upper.* The evidence of the greater age of the lower is not equally conclusive at all points, but nowhere is the relationship between the two such as to necessitate the assumption of the greater age of the upper.

We must conclude, therefore, that the front of the ice became deeply embayed as it retreated from the line of the moraine, and that for a time the waters of the lake sank about 70 feet below the Madison level. During this stage the lower terraces and deltas observed in the intra-moraine basin were formed, and perhaps also the gravel beds without the moraine near Madisonville, 80 feet below the maximum water level. The Upper Preakness stage was probably a short one, since the terraces are not of great size and deposits of this character were undoubtedly made very rapidly. In order to account for the lowering of the lake level it is necessary to suppose that the lake had at this time a subglacial outlet. This might readily have been brought into existence as the ice retreated towards the Little Falls gap. There are, however, some difficulties involved in this assumption. These will be noticed later.

The Montville stage.—If the higher terraces are younger than the lower, it must be further assumed that the low stage of the lake was followed by a rise of the water approximately to the Madison level. The name Montville is proposed for this stage of the lake. During this stage there were formed the high-level delta plains and terraces north of Parsipanny, near Boonton, north of Montville, at Jacksonville, north of Upper Preakness, west of Haledon and at Caldwell. The ice retreated a little between the Upper Preakness stage and the Montville stage, and the deltas of the latter were built a little back of and above those of the former. In some cases the higher plains reached and partially buried the lower ones. The Montville stage seems to have been a little longer than the Upper Preakness stage. In a few places possible shore-lines have been noted at elevations between those of the Montville stage and those of the Upper Preakness stage, but it has not been possible to correlate them definitely with each other, or to make out their time relationship to other shore-lines. They are best shown on the inner face of the moraine, south of Montville, near Caldwell, and northeast of New Vernon.

If the preceding conclusions as to the relative ages of the Upper Preakness and of the Montville shore-lines be correct, we must conclude that the rise of the water to the Montville level was brought about by the closing of the subglacial outlet. It must be confessed that it is difficult to understand how such an outlet, once established during the retreat of the ice, could again be closed *during the further retreat of the ice*, when its motion was probably diminishing in vigor, and when its rate of melting was very likely increasing, and when it was becoming thinner. Nevertheless, the stopping of the outlet, even under these adverse conditions, seems to be indicated.

The final draining of Lake Passaic.—After the Montville stage had endured for a time sufficient for the formation of the glacial deltas which mark that stage, the ice was melted back so as to permit the escape of the lake drainage through the Little Falls and Paterson gaps. The intra-morainic part of the lake was soon drained to the level of the barrier at Little Falls, 175 to 190 feet. Below this level in the area of the Great Piece and Troy meadows, and perhaps in Black meadows and Hatfield swamp, shallow bodies of water may have lingered until the outlet was brought down to this level. Such bodies of water must have existed for a time, if relative levels were the same as now. As deformation of the basin has taken place since the ice disappeared, it may be that these swampy areas were not then lower than the Little Falls outlet. After the Little Falls outlet was established, a small post-glacial lake remained in the extra-morainic basin over the low land between Second mountain and Long Hill, in the valleys of the Passaic and Dead rivers. It was held at 230 feet by the drift barrier at Stanley, through which the river has since cut a passage.

Judging by the meager developments of the shore features of Lake Passaic save in those cases where the supply of material from the glacier was abundant, their indefinite form in many instances, and their entire absence in localities where they might rationally be expected to exist, we cannot but conclude that the entire life of the lake, was, geologically speaking, brief. During its maximum extension, just before its final draining, Lake Passaic must have been about 30 miles long and 10 miles wide at its widest part. It must have had a maximum depth of about 225 feet in the intra-morainic part, and of about 140 feet in the extra-morainic.

The sequence of events outlined above is based upon the assumption that all the drift in the Short Hills gap is late glacial, and that, until the ice reached the line of the moraine, drainage escaped through this gap at the level of the rock bottom. The presence of the thick deposits of (lacustrine ?) clay in the region of the Great Swamp, which by their relationship to overlying deposits, are clearly shown to antedate the moraine and accompanying overwash plain, indicate that a lake may have existed in the Great Swamp area for a considerable period before the ice of the last epoch formed the moraine.

Three hypotheses concerning a pre-morainic lake in the Lake Passaic region may be considered. (1) Some part, perhaps a large part of the drift filling of the Short Hills gap, may belong to an earlier ice sheet which deposited the extra-morainic drift found more or less abundantly about the lake basin and above the lake level. In this case, the inter-glacial drainage may have been through the Little Falls outlet and Lake Passaic may have come into existence, so soon as the ice of the last epoch closed the Little Falls gap. Under this hypothesis, the Great Swamp clays would be referred to this early stage of the lake's history. In this event we must suppose that the ice advanced very slowly, so slowly that a great thickness of clay accumulated before the deposition of the overlying loam, sand, and gravel, which are contemporaneous with the moraine or which but slightly antedate it. The clays north of the moraine, which are similar to lacustrine clays, are also in general at low levels, and so far as elevation goes, may have been formed in such a lake.

(2) We may conceive that the earlier ice invasion wrought such changes in the preglacial topography, that, after its retreat, a low-level lake occupied the area of the Great Swamp, and perhaps also the lowlands northeast of the moraine. In this inter-glacial lake much of the lacustrine clay may have been formed. We may suppose further that the lake was drained during inter-glacial time by the clearing out of the Short Hills gap. In this case we should expect to find the clays overlain by an old soil developed after the lake was drained. Above this old

soil would come whatever deposits were made in the lake basin during the later glacial invasion. So far as known, such an old soil does not exist, but observations are not numerous enough to prove its absence.

(3) The third hypothesis differs from the second only in the assumption that the inter-glacial lake lasted until the later ice invasion, and was continuous in time with the lake formed in consequence of that ice invasion.

The first hypothesis makes the clays, so far as they are lacustrine, entirely late-glacial. The great objection to it is the very long time required for the advance of the ice, in order to permit the formation of so great a body of clay, compared to the brief time of its maximum extension and retreat. The retreat must have been rapid, since the silts and sands correlated in time of origin with the moraine, are not buried by later deposits. The second hypothesis makes most of the clays early glacial and inter-glacial, and seems to demand an old soil separating these deposits from later ones. Such a soil is not known to exist. The third hypothesis makes most of the clays early glacial and inter-glacial, and it demands their transition upward into the later deposits without a break. Sufficient data are not available to permit a decision in favor of any one of these hypotheses.

DEFORMATION OF THE LAKE BASIN.

The highest shore-lines of Lake Passaic are no longer at a constant elevation with reference to the present sea level. At the southern end of the lake, the highest shore-line has an elevation of 345 feet;[1] at the Moggy Hollow outlet, about 356 feet; at Morristown about 376 feet; at Boonton about 394 feet; at Montville about 398 feet; at Jacksonville, 408-9 feet; north of Upper Preakness, about 412 feet. On the eastern side of the lake the shore-line increases in elevation from south to north. At Mt. Bethel it has an elevation of 350 feet; at West Summit probably 367 feet; at Caldwell, 385 to 390 feet; at Haledon it is 405 feet.

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[1] Elevations in most cases were determined accurately by two men working with a rod and level, from bench marks established during the topographical survey of the state.

These figures show that the shore-line rises from 345 feet to 412 feet from the southern to the northern end of the lake. The shore-lines, however, do not rise most rapidly in the direction of the longer axis of the lake, from southwest to northeast, but rather from south to north. Calculated in this direction, the rise is 67 feet in 25 miles, giving a gradient of two and two-thirds feet per mile. This rise northward is by no means regular. Within short distances, the gradient varies from nearly four feet per mile to less than one foot. In one or two instances, notably along the subaqueous overwash plain, the shore-line, after making all possible allowances, seems to be slightly lower than at points further south and southwest. The differential northward elevation of the lake basin, following the withdrawal of the ice, did not proceed with a constant gradient. It was rather of the nature of an irregular warping and incipient buckling, with the greatest rise to the northward.

The deformation of the shore-lines occurred after the lake was drained, rather than during different stages of the lake. This is shown by the fact that the Upper Preakness shore-line is everywhere about 70 feet below the Montville level, whereas, if any deformation had occurred in the interval between these two stages, their shore-lines would not be essentially parallel.

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